1 (currently amended). A method for securing and controlling a micro-mirror, the method comprising:

directly connecting three or more supporting springs to a micro-mirror at selected spaced apart locations to provide a restoring force for each of at least two rotational degrees of freedom of movement of the micro-mirror, where the spring connection locations form a conceptual polygon and the supporting springs maintain a length-to-thickness ratio selected so that the supporting springs operate primarily in a tensile mode; ~~and~~

electro-statically actuating the micro-mirror by three or more spaced apart driving electrodes located adjacent to the micro-mirror, with each driving electrode being independently controlled [[,]] ; and

~~wherein the supporting springs maintain a length-to-thickness ratio selected so that the supporting springs operate primarily in a tensile mode ; and~~

providing the micro-mirror with a frame including dielectric material positioned close to at least one edge of the micro-mirror and positioned between a first material layer that contains the micro-mirror and a second material layer that contains the supporting springs.

2. The method of claim 1, further comprising providing a voltage of less than 100 volts between said micro-mirror and said electrodes.

3. The method of claim 1, further comprising associating at least two enhancement springs with at least one of said supporting springs to enhance stability and to provide a selected tilting range for said micro-mirror.

4. The method of claim 3, further comprising orienting at least one of said enhancement springs perpendicular to said associated supporting spring.

5. The method of claim 3, further comprising fanning out at least one of said enhancement springs from said associated supporting spring with a selected angle to said associated supporting spring.

6. The method of claim 5, further comprising selecting said angle between said supporting spring and at least one of said associated enhancement springs to be between 90 degrees and 180 degrees.

7 (currently amended). The method of claim 3, further comprising configuring at least one of said supporting springs and said associated enhancement springs so that said restoring force between said at least one supporting spring and said micro-mirror increases with a measure u of spring deflection approximately as $a \cdot u + b \cdot u^2 + c \cdot u^3$, where a, b and c are selected ~~parameters~~ non-zero numbers.

8 (currently amended). The method of claim 3, further comprising configuring at least one of said supporting springs and said associated enhancement springs so that said restoring force between said at least one supporting spring and said micro-mirror increases with a measure u of spring deflection approximately as $a \cdot u + c \cdot u^3$, where a and c are selected parameters non-zero numbers.

9 (canceled). The method of claim 1, further comprising providing said micro-mirror with a frame including dielectric material positioned close to at least one edge of said micro-mirror and positioned between a first material layer that contains said micro-mirror and a second material layer that contains said

supporting springs.

10 (currently amended). The method of claim [[9]] 1, further comprising providing said dielectric material as a discontinuous buried layer.

11 (canceled). The method of claim 1, further comprising providing one or more neutral electrodes positioned adjacent to said micro-mirror, where the neutral electrodes and said adjacent micro-mirror have substantially the same electrical potential.

12 (currently amended). The method of claim [[11]] 37, further comprising locating at least one of said neutral electrodes substantially at the center of said micro-mirror.

13. The method of claim 1, further comprising positioning said supporting springs and recessing said micro-mirror so that a net electro-static force generated by said driving electrodes is directed outside of said conceptual polygon when said micro-mirror is in operation.

14. The method of claim 1, further comprising recessing said micro-mirror in at least one selected location to connect said supporting springs thereto to provide a selected tilting range for said micro-mirror.

37 (new). A method for securing and controlling a micro-mirror, the method comprising:

directly connecting three or more supporting springs to a micro-mirror at selected spaced apart locations to provide a restoring force for each of at least

two rotational degrees of freedom of movement of the micro-mirror, where the spring connection locations form a conceptual polygon and the supporting springs maintain a length-to-thickness ratio selected so that the supporting springs operate primarily in a tensile mode;

electro-statically actuating the micro-mirror by three or more spaced apart driving electrodes located adjacent to the micro-mirror, with each driving electrode being independently controlled, and

providing one or more neutral electrodes positioned adjacent to the micro-mirror, where the neutral electrodes and the adjacent micro-mirror have substantially the same electrical potential.

38 (new). The method of claim 37, further comprising providing a voltage of less than 100 volts between said micro-mirror and said electrodes.

39 (new). The method of claim 37, further comprising associating at least two enhancement springs with at least one of said supporting springs to enhance stability and to provide a selected tilting range for said micro-mirror.

40 (new). The method of claim 39, further comprising orienting at least one of said enhancement springs perpendicular to said associated supporting spring.

41 (new). The method of claim 39, further comprising fanning out at least one of said enhancement springs from said associated supporting spring with a selected angle to said associated supporting spring.

42 (new). The method of claim 41, further comprising selecting said angle between said supporting spring and at least one of said associated enhancement springs to be between 90 degrees and 180 degrees.

43. The method of claim 39, further comprising configuring at least one of said supporting springs and said associated enhancement springs so that said restoring force between said at least one supporting spring and said micro-mirror increases with a measure u of spring deflection approximately as $a \cdot u + b \cdot u^2 + c \cdot u^3$, where a, b and c are selected parameters.

44 (new). The method of claim 39, further comprising configuring at least one of said supporting springs and said associated enhancement springs so that said restoring force between said at least one supporting spring and said micro-mirror increases with a measure u of spring deflection approximately as $a \cdot u + c \cdot u^3$, where a and c are selected parameters.

[0010] Fig. 3 illustrates a top view of the micro-mirror subsystem of Fig. 2 according to one example of the present invention.

[0011] Fig. 4 illustrates a three dimensional view of the micro-mirror subsystem of Fig. 3 with each layer separately shown.

[0012] Fig. 5 illustrates a top view of the micro-mirror subsystem of Fig. 2 according to another example of the present invention.

[0013] Fig. 6 illustrates a zoom-out view of the micro-mirror subsystem showing multiple bond pads along the borders of the subsystem.

[0014] Fig. 7 illustrates a zoom-in view of the micro-mirror with regard to multiple driving electrodes underneath the mirror.

[0015] Figs. ~~8a-c~~ 8a, 8b and 8c illustrate a micro-mirror of other geometrical shapes and their corresponding mechanisms for securing supporting springs thereto.

[0016] Figs. ~~9a-b~~ 9a and 9b illustrate other arrangements of the supporting springs according to the present invention.

[0017] Fig. 10 illustrates a sectional view of a micro-mirror with re-enforcing oxide layer according to one example of the present invention.

[0018] Fig. 11 illustrates a relationship between a net restoring force of the supporting springs along with enhancement springs and a deflection thereof.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0019] The present invention discloses a class of electro-statically actuated micro-machined mirror designs that are mechanically stable when actuated. Although the

produces a substantially vertical net electro-static force that causes the desired mirror tilting movement. Because of the existence of the neutral electrode 93, the electrostatic forces act primarily on the outer portion of the mirror, thereby further assuring that the net electro-static force vector acts on the mirror outside the conceptual polygon 66 (Figs. 3-5). The driving electrodes may be covered with a dielectric thin film (such as silicon dioxide or silicon nitride) to prevent catastrophic failure due to shorting, or to enhance the electric field and the attraction force to the mirror.

[0029] Figs. ~~8a-c~~ 8a, 8b and 8c illustrate a micro-mirror of other geometrical shapes and their corresponding mechanisms for securing supporting springs thereto. For example, in Fig. 8a, the micro-mirror 94 is of a triangular shape, and the supporting springs are attached to each side of the triangular mirror. In Fig. 8b, the supporting springs 96 are attached to the vertices of the triangular mirror. Fig. 8c illustrates another geometrical shape of the micro-mirror 98, which is a hexagon with supporting springs connected to the vertices thereof.

[0030] Figs. ~~9a-b~~ 9a and 9b purposefully demonstrate that the arrangement of the supporting springs does not need to possess a rigid symmetry as those shown in Figs. 2-8c. In Fig. 9a, the micro-mirror 100 is a square one and two of the supporting springs are attached to two corners of the mirror, while the other 104 is in the middle of a side. In Fig. 9b, the mirror 106 is of a rectangular shape, and none of the four supporting springs 108 faces directly to another to form a continuous linear axis. They are shifted away from the center line of the rectangular mirror. Although these Figs. indicate that the mirror can be of various shapes and the supporting springs can be arranged asymmetrically, it is understood that the key requirements are to secure the mirror so that it is stable under electrostatic actuation and has at least two rotational degrees of freedom of movement. The stability prevents surface-to-surface contact which in turn prevents stiction from developing.

Reply To Examiner's Remarks

Claims 1-8, 10, 12-14, as amended, and new claims 37-44 are presented for consideration.

The Examiner objects to Figure 1 of the drawings, noting that this Figure should be labeled as Prior Art. An amended Figure 1, labeled as Prior Art, is submitted herein for approval by the Examiner.

The Examiner objects to an unspecified drawing, believed to be Figure 6, noting the driving electrode 91 is not explicitly shown in this Figure. An amended Figure 6, labeling the driving electrode 91, is submitted herein for approval by the Examiner.

The Examiner objects to the Brief Description of the Drawings, asserting the "Figs. 8a-c" and "Figs. 9a-c" should be re-expressed as "Figs. 8a, 8b and 8c" and as "Figs. 9a and 9b," respectively. These changes are made herein on pages 3 and 8 on the specification.

The Examiner objects to the title and requires submission of a new title for the application. The Applicants have reconsidered the present title and believe that the present title does describe the invention. The Applicants ask the Examiner to recommend a title that the Examiner believes adequately describes the invention.

The Examiner rejects claims 7 and 8 under 35 U.S.C. 112, second paragraph, as indefinite, noting the parameters a, b and c are not adequately defined. Claims 7 and 8 are amended herein to more refer to a, b and c as non-zero numbers.

The Examiner rejects claims 1-8 and 13-14 under 35 U.S.C. 103(a) as obvious in view of cited combinations of U.S. Patent No. 6,504,653, issued to Peeters et al, U.S. Patent No. 6,128,122, issued to Drake et al, U.S. Patent No. 5,629,794, issued to Magel et al, U.S. Patent No. 5,739,941, issued to Knipe et

al, and U.S. Patent No. 5,894,090, issued to Tang et al.

The Examiner indicates that claims 9-12 would be allowable if rewritten as independent claims including the base claim and any intervening claims. Claim 9 is canceled herein, and claim 1 is amended to include the limitations of former claim 9. Claim 10 is amended to depend upon the amended claim 1. Claims 2-8 and 13-14 now depend upon amended claim 1 and are believed to be allowable if amended claim 1 is allowable.

Claim 11 is canceled herein, and former claims 1 and 11 are combined as new claim 37. Claim 12 is amended herein to depend upon new claim 37. New claims 38, 39, 40, 41, 42, 43 and 44, introduced herein, depend upon new claim 37 and correspond to the respective claims 2, 3, 4, 5, 6, 7 and 8 and are believed to be allowable if new claim 37 is allowable.

The Applicants have responded to the objections and rejections, have rewritten claims 1 and 9 as amended claim 1, have amended claim 10 to depend upon amended claim 1, have rewritten claims 1 and 11 as new claim 37, and have amended claim 12 to depend upon new claim 37. The Applicants request that the Examiner pass the application, including claims 1-8, 10 and 12-14, as amended, and new claims 37-44, to issue as a U.S. patent.

Respectfully Submitted,

Date: 26 February 2004

John Schipper

Patent representative for Applicants